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GROWTH OF WHITE PINE IN RELATION TO SOILS AND TOPOGRAPHY IN SOUTHEASTERN OHIO

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Growth of White Pine in Relation to Soils and Topography in Southeastern Ohio[1]

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INTRODUCTION

Eastern white pine (*Pinus strobus* L.) has a limited natural range in Ohio, occurring as individual trees and in small stands, primarily in the eastern part of the state. However, the species has been planted extensively in Ohio. The most recent forest survey (10) estimated that there were approximately 125,000 acres of white pine in Ohio, most having been planted on old-field sites since the early 1930's. During the period 1961 to 1980, nearly 63 million white pine seedlings were distributed by nurseries operated by the Ohio Department of Natural Resources (ODNR) to land owners for planting throughout the state.

Numerous studies have shown that various combinations of soil and/or topographic factors can be combined in multiple regression equations to provide accurate, indirect estimates of height growth and site quality for a number of tree species. Most studies have shown closest relationships between growth and factors which affect available soil moisture. Where sites are relatively flat and/or soils uniform, site quality estimates have often been based on soil properties alone (8, 18, 21). Where surface features are not uniform, topographic factors have often been included to increase the precision of prediction equations (2, 7, 17, 20). Fewer studies have found close correlations of soil chemical factors with growth or have included chemical factors in equations (14, 15, 16).

Information on growth of white pine in Ohio in relation to changing site conditions is limited. Studies in other areas indicate considerable differences in growth on areas of varying site quality. Thirty-five year site indices for natural white pine stands in New England ranged from approximately 35 to 55 feet (11), while in the Lake States they ranged from approximately 27 to 56 feet (12). Growth of white pine plantations in the southern Appalachians was considerably better, with 35-year site indices of approximately 49 to 98 feet (19).

In earlier studies (5, 6), systems were developed for evaluating height growth and site quality in white pine stands in the residual soils area of Ohio, using growth intercept measurements and growth intercepts in

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combination with soil and/or topographic factors. The purpose of the present study was to develop soil-site equations containing only soil and/or topographic factors which could be used for estimating potential height growth and site quality of areas to be planted with white pine, or in young stands for which conventional site index curves or growth intercept techniques cannot be used.

METHODS

Data for this study were collected in white pine stands planted on old-field sites in the residual soils region of southern and eastern Ohio. Pure and mixed plantings (with other conifers and/or hardwoods) were used, with white pine representing 30 to 100% (average 75%) of the basal area in stands. A total of 202 (162 study and 40 check) plots, each containing 3 to 5 dominant and/or codominant trees (free of insect and disease damage, snow or ice breakage) were measured. Plots were kept as small as possible to minimize soil and topographic variation within plots and a full range of topographic conditions was represented in the sample. Soils on plots were well and moderately well drained, with total depths ranging from 10 to 42 inches (the maximum depth sampled). Few stands were found growing on poorly or somewhat poorly drained soils and trees growing on such soils were excluded from the study.

For trees on each plot, total age was determined from plantation records and age at breast height (BH) was determined from increment cores. Only plots which were 25 years or older at BH were used. Total age of trees from planting ranged from 29 to 52 years and averaged 39 years for all plots. Age at BH ranged from 25 to 47 years and averaged 33 years for all plots. Total height, height at 25 years from planting, and height for 25 years of growth beginning with the BH annual increment were measured using a Spiegel Relaskop.

For each plot, aspect, slope shape (convex, even, or concave), slope percent, total slope length, length of slope above plots, and slope position (percent distance from ridge) were determined. Soil profile descriptions were made using averages from two soil pits dug on each plot. In addition, composite soil samples were collected from the A and B_2 horizons on each plot. Samples were air dried, rolled, and passed through a 2-mm sieve. Soil pH; lime test index (LTI); available P; exchangeable K, Ca, and Mg; cation exchange capacity (CEC); and percent base saturation were determined by the Research Extension Analytical Laboratory (REAL) at the Ohio Agricultural Research and Development Center (OARDC). Soil texture was determined using hydrometer analysis (4) and soil moisture retention (1/3, 2/3, 1, 3, 5, 10, and 15 atm) was determined using porous plate apparatus.

All statistical analyses were run using plot data and averages for the 3 to 5-tree plots as data entries. During statistical analyses, several transformations of measured heights, age, topographic, and soil variables were tested to obtain the best fit to study data. Only two significantly improved relationships: [cos(azimuth −45)+1] which places optimum azimuth at 45°

as suggested by Beers *et al.* (3); and l/total soil depth. Means and standard deviations of tree, topographic, and soil variables sampled are shown in Table 1.

Correlation analysis was used to test relationships between heights of trees and years to reach BH. Two methods were used to screen topographic and soil variables for inclusion in final multiple regression analyses. Initial stepwise multiple regression runs were made to test relationships between tree heights and three groups of independent variables (each in combination with tree age): 1) topographic and field measured soil profile descriptions, 2) laboratory determined soil textures and soil moisture retention

TABLE 1.—Means and Standard Deviations for Tree, Topographic, and Soil Variables.

Variable	Mean	Standard Deviation
Tree height, BH and above, ft	69	10.2
Tree age, BH, yr	33.3	4.4
Plot azimuth, degrees	167	103
Plot slope, %	22	12
Total slope, length, yd	80	58
Plot distance from ridge, %	51	29
Total soil depth, inches	25	7.9
A soil horizon:		
Thickness, inches	5.5	2.4
Sand, %	25	14
Silt, %	52	11
Clay, %	23	6
Moisture retention, 1/3 atm, %	28	4
Moisture retention, 15 atm, %	10	3
pH	4.9	0.39
Phosphorus, lb/acre	17	13
Potassium, lb/acre	112	37
Calcium, lb/acre	970	553
Magnesuim, lb/acre	153	103
Cation exchange capacity, me/100 g	14	3.3
Base saturation, %	23	12
B soil horizon:		
Thickness, inches	17	5.7
Sand, %	22	14
Silt, %	51	11
Clay, %	27	9
Moisture retention, 1/3 atm, %	29	4
Moisture retention, 15 atm, %	9	4
pH	4.9	0.44
Phosphorus, lb/acre	16	20
Potassium, lb/acre	128	56
Calcium, lb/acre	966	880
Magnesuim, lb/acre	254	248
Cation exchange capacity, me/100 g	11	5.1
Base saturation, %	30	18

values, and 3) laboratory determined soil chemical factors. In addition, correlation analysis was used to test relationships between all soil and topographic factors and 25 years of growth of trees beginning at BH (the maximum age for which heights were available for all trees).

Based on those screenings, three topographic factors (aspect, percent distance from ridge, and slope percent); two soil descriptive factors (total soil depth and thickness of the A horizon); one soil physical factor (moisture retention of B horizon soil at 15 atm); and one soil chemical factor (percent base saturation of B horizon soil) were selected and used in combination with age in multiple linear regression analyses to develop equations for estimating height growth of white pine. Of those, only four contributed significantly to the equations: aspect, percent distance from ridge, total soil depth, and thickness of A horizon. (Because of varying soil conditions, A horizon thickness varied to include individual or combinations of A_1, A_2, and/or A_p horizons.) Using those equations, actual heights of trees on the 162 study and 40 check plots were compared with computed heights. No significant differences were noted between study and check plots, and data were combined and regression analyses were rerun for all 202 plots to obtain final regression equations.

RESULTS AND DISCUSSION

Early Height Growth. From 4 to 12 years were required for individual trees on plots to reach BH; plot averages ranged from 4.5 to 10.7 years. Time required to reach BH showed little correlation with total height ($r = -0.099$), height from BH to the growing tip ($r = -0.143$), 25-year height based on 25 years of growth after planting ($r = 0.102$), or 25 years of growth above BH ($r = 0.117$). This indicates that factors such as size of planting stock, planting method, vegetative competition, insect and animal damage, etc. which can affect establishment and early growth of seedlings are not closely related to site conditions which affect later growth. Similar results have been noted in other studies (1, 9, 13). Inclusion of height and age data from below BH introduces an unrelated error into site index estimates, and that error will be most serious in younger stands. In sections which follow, height growth estimates are based on *height and age for growth from the base of the BH internode to the growing tip.*

Growth and Site Index in Relation to Soil and Topographic Factors. Using tree age and the four soil and topographic factors which were significant in equations, four separate multiple regression equations were developed for estimating height growth and site quality of white pine planted on old-field sites in the residual soils area of Ohio. Those equations are:

1) Height, ft = 7.823 + 1.586(Age) + 0.120(Percent Distance from Ridge) + 2.294[cos (Azimuth — 45) + 1] $r^2 = 0.670$, s.e. = 5.73

2) Height, ft = 17.841 + 1.525(Age) + 0.107(Percent Distance from Ridge) —160.151(1/Total Soil Depth, inches) + 1.987[cos(Azimuth — 45) + 1] $r^2 = 0.729$, s.e. = 5.20

3) $\text{Height, ft} = 5.776 + 1.496(\text{Age}) + 0.105(\text{Percent Distance from Ridge}) + 0.126(\text{Thickness of A Horizon, inches}) + 1.900[\cos(\text{Azimuth} - 45) + 1]$
   $r^2 = 0.732$, s.e. = 5.18

4) $\text{Height, ft} = 13.288 + 1.479(\text{Age}) + 0.100(\text{Percent Distance from Ridge}) + 0.812(\text{Thickness of A Horizon, inches}) - 110.973(1/\text{Total Soil Depth, inches}) + 1.797[\cos(\text{Azimuth} - 45) + 1]$ $r^2 = 0.758$, s.e. = 5.01

In all equations, age accounted for 51% of the total variation in heights of trees.

These four equations should permit estimation of height growth and/or site quality of white pine using a variety of data which might be available or which could be determined easily in the field. Equation 1, containing only topographic factors, accounts for approximately two-thirds of the total variation in heights of trees on study plots and estimates based on the equation should be within acceptable limits for most purposes (see next section). Adding either total soil depth (Equation 2) or thickness of the A soil horizon (Equation 3) to equations increased the variation accounted for by approximately 6%, while adding both soil factors (Equation 4) increased the total variation accounted for in the equation to more than 75%. In studies with black oak (*Quercus velutina* Lam.) carried out in the same geographic area, Carmean (7) found that equations containing only topographic factors accounted for 75% of the variation in tree heights, while 84% of the variation was accounted for when a combination of soil and topographic factors was used.

Although Equations 1 to 4 can be used to compute site index values for any base age, they can be used most accurately for ages within the range of those of trees sampled in the study. Accordingly, Equations 1 to 4 were used to compute estimated site indices for white pine using a 35-year base age rather than the 50-year base commonly used throughout most of the North Central and Northeastern U. S. and Canada (Tables 2 to 5). The range of 35-year site indices shown in Tables 2 to 5 (58 to 84 ft) is approximately the same as that reported in an earlier study in which site index estimates for white pine were based on growth intercept measurements in combination with soil and topographic factors (5, 6). Those site indices compare favorably with 35-year site indices (based on total height and age) reported by Vimmerstedt (19) for white pine plantations in the southern Appalachians. They are equal to or better than 50-year site indices (based on total height and age) reported for natural stands of white pine in New England (11) and the Lake States (12). They are also approximately the same as 50-year site indices (based on total height and age) of black oak growing in the same geographic area as the study reported here (7).

Reliability of Multiple Regression Equations for Estimating Height Growth. The reliability of the four equations developed for estimating height growth and site index in white pine stands was tested in two ways. Before data were combined for all plots, average 25-year and total heights (from BH to growing tip) for trees on the 162 study plots were compared with values computed using the different equations. All equations predicted 25-year and total heights within ±5% of actual heights on 45% or more of the plots, within ±10% on more than 80% of the plots, and within ±15% on 94% or more of the plots. In addition, similar comparisons were made for the 40 original check plots. For those, computed heights were within ±5% of actual heights on 45% or more of the plots, within ±10% on 70% or more of the plots, and within ±15% on more than 95% of the plots. Computed and actual heights differed by more than 20% on only one (study) plot. After check and study plots were combined to give Equations 1 to 4, predicted heights were within ±5% of actual heights on 44 to 53% of the plots, within ±10% on 82 to 88% of the plots, and within ±15% on 95 to 99% of the plots. In all cases (study, check, and combined data), Equation 1 containing only topographic factors was the least reliable and Equation 4, which contained topographic and both soil factors, was the most accurate.

USE OF TABLES 2 TO 5 FOR PREDICTING SITE INDEX IN WHITE PINE STANDS

A number of factors should be considered to insure that good estimates of site indices of white pine stands are obtained when using Tables 2 to 5. First, the study on which those estimates are based was carried out in stands on well and moderately well drained soils in the residual soils area of southern and eastern Ohio. Accuracy of predictions for white pine stands growing in other areas or on somewhat poorly drained soils has not been tested.

Data collected for estimating site index should be representative of the area for which estimates are to be made. Many stands may cover most of a slope, and soil factors and even aspect may vary greatly within the stand. Site index estimates will be most accurate if separate estimates are made for different portions of such stands. For example, a large stand stretching from ridgetop to bottom of the slope might be subdivided into three portions: upper, mid, and lower slope, and estimates (of aspect and/or soil factors) made for each portion. If estimates are desired for the whole stand, aspect and/or soil measurements should be made throughout the stand and averages for those measurements used in conjunction with the mid-slope position for estimating average site index. If soil values are used, measurements should be made at a number of locations — probably a minimum of three in smaller stands and possibly five to ten or more in larger stands, depending on size and variability.

Finally, Tables 2 to 5 present site index values on a 35-year base rather than the traditional 50-year base commonly used for estimating site quality for tree species in Ohio. Although this was done primarily because of the range of ages of trees sampled in the study, the site index values presented in Tables 2 to 5 reflect growth rates for white pine which can provide a variety of products with relatively short rotations. With proper management, it should be possible to produce adequate volumes of small dimension and/or "chip" products in 35 years or less even on poorer sites. On better sites, height and diameter growth should be adequate to produce higher value sawlog-sized products with similar rotations. On study plots, 35-year-old trees (at BH) reached diameters up to 19 inches.

TABLE 2.—Estimated 35-Year Site Index (Based on Age at BH and Height from BH to Growing Tip) of White Pine Based on Slope Position and Aspect.*

Slope Position (Percent Distance from Ridge)	Aspect NE	Aspect NW and SE	Aspect SW
	Site Index, ft		
Ridge (0%)	68	66	63
Upper (75%)	71	69	66
Mid (50%)	74	72	69
Lower (75%)	77	75	72
Bottom (100%)	80	78	75

*Site index calculated from. height, ft = 7.823 + 1.586 (age) + 0 120 (percent distance from ridge) + 2 294 [cos(azimuth − 45) + 1].

TABLE 3.—Estimated 35-Year Site Index (Based on Age at BH and Height from BH to Growing Tip) of White Pine Based on Aspect, Total Soil Depth, and Slope Position.*

Aspect	Total Soil Depth	Slope Position (Percent Distance from Ridge)				
		Ridge (0%)	Upper (25%)	Mid (50%)	Lower (75%)	Bottom (100%)
	Inches	Site Index, ft				
NE	12	62	65	67	70	73
	18	66	69	72	74	77
	24	69	71	74	77	79
	30	70	72	75	78	81
	36	71	73	76	79	81
	42	71	74	77	79	82
NW and SE	12	60	62	65	68	71
	18	63	67	70	72	75
	24	66	69	72	75	77
	30	68	70	73	76	79
	36	69	71	74	77	80
	42	69	72	75	77	80
SW	12	58	61	63	66	69
	18	62	65	68	70	73
	24	65	67	70	73	75
	30	66	69	71	74	77
	36	67	69	72	75	78
	42	67	70	73	75	78

*Site index calculated from height ft = 17 841 + 1 525 (age) + 0 107 (percent distance from ridge) − 160 151 (1/total soil depth inches) + 1 987 [cos(azimuth − 45) + 1]

TABLE 4.—Estimated 35-Year Site Index (Based on Age at BH and Height from BH to Growing Tip) of White Pine Based on Aspect, Thickness of A Soil Horizon, and Slope Position.*

Aspect	Thickness of A Horizon	Slope Position (Percent Distance from Ridge) Ridge (0%)	Upper (75%)	Mid (50%)	Lower (25%)	Bottom (100%)
	Inches	Site Index, ft				
NE	2	64	67	69	72	75
	4	66	69	72	74	77
	6	69	71	74	77	79
	8	71	74	76	79	81
	10	73	76	78	81	84
NW and SE	2	62	65	68	70	73
	4	64	67	70	72	75
	6	67	69	72	75	77
	8	69	72	74	77	80
	10	71	74	76	79	82
SW	2	60	63	66	68	71
	4	63	65	68	70	73
	6	65	68	70	73	75
	8	67	70	72	75	78
	10	69	72	75	77	80

*Site index calculated from height ft = 5 776 + 1 496 (age) + 0 105 (percent distance from ridge) + 1 126(thickness of A horizon, inches) + 1 900 [cos(azimuth − 45) + 1]

TABLE 5.—Estimated 35-Year Site Index (Based on Age at BH and Height from BH to Growing Tip) of White Pine Based on Aspect, Total Soil Depth, Thickness of A Soil Horizon, and Slope Position.*

Aspect	Total Soil Depth	Thickness of A Horizon	Slope Position (Percent Distance from Ridge): Ridge (0%)	Upper (25%)	Mid (50%)	Lower (75%)	Bottom (100%)
	Inches		Site Index, ft				
NE	12	3	62	64	67	69	72
		6	64	67	69	72	74
		9	67	69	72	74	77
	24	3	67	69	72	74	77
		6	69	71	74	76	79
		9	71	74	76	79	81
	36	3	68	70	73	76	78
		6	70	73	75	78	80
		9	73	75	78	80	83
NW and SE	12	3	60	63	65	68	70
		6	63	65	68	70	72
		9	65	67	70	72	75
	24	3	65	67	70	72	75
		6	67	70	72	75	77
		9	70	72	75	77	80
	36	3	66	69	71	74	76
		6	69	71	74	76	79
		9	71	74	76	79	81
SW	12	3	58	61	63	66	68
		6	61	63	66	68	71
		9	63	66	68	71	73
	24	3	63	65	68	70	73
		6	65	68	70	73	75
		9	68	70	73	75	78
	36	3	64	67	69	72	74
		6	67	69	72	74	77
		9	69	72	74	77	79

*Site index calculated from: height, ft = 13.288 + 1.479 (age) + 0.100 (percent distance from ridge) + 0.812 (thickness A horizon, inches) − 110.973 (1/total soil depth, inches) + 1.797 [Cos(45 − azimuth) + 1]

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